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New research issues in sous-vide cooking

Mia Schellekens

Most research on sous-vide cooking is dedicated to microbiological aspects, especially exploration of the use of additional hurdles so that an imperfect chill chain can still guarantee safe products. Legislation is moving towards the application of general food hygiene regulations and the requirement to use HACCP (hazard analysis and critical control point) principles. Sector-specific guidelines are being developed in many countries. Research on nutritional quality indicates that sous-vide cooking is beneficial for the retention of vitamins and unsaturated fatty acids. Information on the sensory quality of sous-vide foods compared with that of traditionally cooked foods is ambiguous.

Sous-vide cooking or vacuum cooking is defined as: 'raw materials or raw materials with intermediate foods that are cooked under controlled conditions of temperature and time inside heat-stable vacuumized pouches'[1]. Lower temperatures (usually under 100°C) and longer cooking times than those used in traditional cooking are typically used. The lowest temperatures are used to cook fish and meat (e.g. below 70°C); higher temperatures are used to cook vegetables (e.g. 95°C). The amount of residual air in the package is dependent on the type of product inside the package. Vulnerable products or products that contain hot sauces cannot be fully vacuumized, and a typical value for the residual pressure inside the package is 120 mbar. For firm products, the residual pressure inside the package can be as low as 10 mbar.

The packaging material must fulfil several tasks, and therefore meet several specifications: it must be resistant to high temperatures, and have low permeability to gases (O_2, vapour), sufficient mechanical strength and limited migration of plastic constituents (food grade). After heating, the products are cooled to temperatures in the range 1–8°C. The shelf life of sous-vide products is dependent on both the heating process used for cooking and the temperature at which they are subsequently stored. The heat treatment applied results primarily in the destruction of vegetative cells; spores will often survive the mild heat-processing conditions. In general, shelf lifes vary in the range 6–42 d. The main advantages of sous-vide cooking compared with traditional cooking are economic (e.g. better use of labour and equipment through centralized production) and qualitative (e.g. reduced need for flavour enhancers, better preservation of vitamins, retention of most of the original food juices). However, the anaerobic conditions inside sous-vide packages can give rise to botulism if toxinogenic strains of *Clostridium botulinum* are present and temperature abuse of a product containing this microorganism

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subsequently occurs. This necessitates specialized equipment, higher training and monitoring costs.

In September 1992, a review study on sous-vide cooking was published[1]. This report and work from other researchers were presented at the First European Sous Vide Cooking Symposium[2] and updated recently[3]. New issues in microbiological aspects of sous-vide cooking, changes in legislation and food manufacturing practices, as well as sensory and nutritional aspects are discussed in this review article.

New issues in microbiological aspects of sous-vide cooking

Additional hurdles

Because there is doubt about whether refrigeration alone is sufficient to assure the safety of sous-vide products, much work is now being focused on the formulation of products with additional hurdles [low pH, low water activity (a_w), added organic acids and protective cultures] to reduce microbiological hazards. Hurdles are a combination of several factors that together ensure the microbial safety and stability of a food even though the different factors alone are insufficient to obtain stable and safe food.

The effects of sodium lactate and storage temperature on toxigenesis (toxin production) by non-proteolytic *C. botulinum* spores inoculated in processed sous-vide beef, chicken breast and salmon were explored by Meng and Genigeorgis[4]. The results in Table 1 show that the addition of sodium lactate significantly delayed toxigenesis in all three products. Lower storage temperatures enhanced the inhibitory effect of this additive on *C. botulinum* toxigenesis in the three food types tested. Taking into account the anticipated low levels of *C. botulinum* spores in meat products and the effect of thermal processing, the authors suggest that the use of ≥2.4% sodium lactate in such products and storage at ≤12°C will inhibit toxigenesis for time periods well beyond their anticipated shelf lifes of 3–6 weeks. Salmon was a more conducive medium for toxigenesis than either beef or chicken at 4–16°C. Sous-vide processing of raw fish, which are known for their frequent contamination with *C. botulinum* at significant levels, may require special formulations, as well as special heat processing and storage temperature standards to obtain extended safe marketing periods.

Table 1. Effects of storage temperature, sodium lactate and product type on the toxicity time of *Clostridium botulinum* in sous-vide products[a]

Product	Sodium lactate (%, w/w)	Time to produce toxin (days) 4°C	8°C	12°C	30°C
Beef	0	90	8	4	1
	2.4	>90	90	>40	3
	4.8	>90	>90	>40	6
Chicken	0	90	16	12	2
	1.8	>90	60	>40	4
	3.6	>90	>90	>40	6
Salmon	0	60	8	4	1
	2.4	90	12	6	2
	4.8	>90	>90	>40	4

[a] Adapted from Ref. 4

Simpson *et al.*[5] carried out challenge studies to evaluate the safety of a sous-vide-processed spaghetti and meat-sauce product inoculated with proteolytic *C. botulinum* types A and B spores. The product was reformulated to obtain samples with a range of pH and a_w values (a_w range 0.992–0.972, pH range 4.5–6.0). Samples were processed at 75°C for 36 min [equivalent to a 13 log cfu (colony-forming unit) reduction for *Streptococcus faecium*], and stored at 15°C. Toxin was detected in samples with a pH >5.5 after 14–21 d, and in those with a pH of 5.25 after 35 d. Toxin was not detected in any samples with a pH of <5.25 within 42 d storage at 15°C. Those samples with a pH of 5.75 or 6.0 were visibly spoiled (i.e. swollen owing to CO_2 production) before toxigenesis was detected. However, in those samples with a pH of 5.5 or 5.25, toxigenesis preceded spoilage. Subsequent studies investigated the effect of the addition of salt on the safety of the sample with a pH of 5.5. Toxin production was inhibited throughout the 42-d storage period at 15°C in samples containing >1.5% salt (w/w).

Ben Embarek *et al.*[6] studied the inhibitory effects of *Enterococcus faecium* as a protective culture. The strains used in this study were isolated from sous-vide-cooked cod fillets; they were non-haemolytic and sensitive to a range of antibiotics, and therefore presumably non-pathogenic. In the presence of 10^7 cfu/ml *E. faecium*, *Listeria monocytogenes* in culture was strongly inhibited at 3°C and partially inhibited at 5°C and 15°C. When cultivated with 10^4 cfu/ml *E. faecium*, *L. monocytogenes* was inhibited only slightly at 15°C and not at all at 3°C or 5°C. The limited effects observed when *E. faecium* was inoculated at a low level could be explained by the relatively higher growth rate of *L. monocytogenes* at 3°C and 5°C. Spontaneous resistance to *E. faecium* bacteriocin was observed at 15°C after 11 d: resistant *L. monocytogenes* cells appeared following a period of effective inhibition. This suggests that resistance developed while the bacteriocin produced by *E. faecium* disappeared. Further investigations are needed to determine the nature and likelihood of the resistance phenomenon, as it could have some serious implications for the future development of the use of bacteriocins in food products.

Crandall *et al.*[7] showed that co-inoculation with *Pediococcus* spp. as the protective culture was unable to inhibit toxin production in sous-vide beef inoculated with *C. botulinum*.

The combined effects of irradiation and sous-vide cooking of chicken breast meat were investigated with respect to the survival and growth of *L. monocytogenes*, shelf life, thiamine content and sensory quality by Shamsuzzaman *et al.*[8] Chicken breasts were inoculated with *L. monocytogenes*, vacuum packed, irradiated with an electron beam (EB) up to 2.9 kGy and cooked to an internal temperature of 65.6°C. Sous-vide cooking alone had a marginal lethal effect on *L. monocytogenes* (only a 0.35 log cfu reduction). However, after the combined treatment of sous-vide cooking and irradiation at 2.9 kGy, the pathogen remained undetectable in the product during an 8-week storage period at 2°C (>5.51 log cfu reduction). Parallel studies on uninoculated breast meat revealed that sous-vide-cooked samples had a shelf life of less than 6 weeks without EB treatment, whereas those samples that were irradiated before sous-vide cooking had a shelf life of at least 8 weeks. Sensory analyses showed that the radiation doses applied had very little effect on either the odour or the flavour of the samples during the time course studied (up to 55 d). The worst mean score for either organoleptic characteristic was '2', which indicated only slight off-odour or slight off-flavour (obtained following sous-vide cooking combined with irradiation at 2.2 kGy and storage for 30 d, or following sous-vide cooking combined with irradiation at 1.1 kGy and storage for 42 d). A slight dose-dependent reduction in thiamine content was observed on all sampling days (cooking alone: 1.05 μg/g thiamine at day 0, cooking and irradiation at 2.9 kGy: 0.92 μg/g thiamine at day 0). Storage at 2°C did not affect the thiamine levels in the irradiated samples.

A slightly changed experimental setup was used for a second experiment[9]. Samples of chicken breast meat inoculated with *L. monocytogenes* were cooked to 71.1°C and then stored at 8°C. The sous-vide cooking alone reduced the *Listeria* counts in the inoculated samples by a 1.48 log cfu reduction. The surviving microorganisms multiplied during storage at 8°C, and the samples spoiled within 2 weeks. The combined treatment (sous-vide cooking and irradiation at 3 kGy) showed almost a 6 log cfu reduction, reducing total viable counts below those associated with spoilage (10^5 cfu/g) for at least 8 weeks at 8°C. These results were confirmed by organoleptic analyses.

Thus, from the most recent findings on the use of hurdle technology for sous-vide products, the use of sodium lactate and of irradiation seem particularly promising.

Influence of food type and medium composition

The growth and inactivation of microorganisms can be largely affected by food type. These findings are important in the assessment of heat treatments required to ensure the safety of sous-vide foods.

Fish is a popular ingredient in sous-vide-cooked food products but, to maintain their intrinsic qualities, fish are cooked at very low temperatures. Ben Embarek and Huss[10] conducted a preliminary study to compare the heat resistance of *L. monocytogenes* in both tryptose-phosphate broth and raw fish during sous-vide cooking (52°C, 2 h). A larger uninjured population of *L. monocytogenes* survived in the initially raw fish than in the broth, indicating that components in the raw flesh may have protected the bacteria. The heat resistance of two strains of *L. monocytogenes* in sous-vide-cooked fillets of cod and salmon was also investigated. Both strains were 1–4-fold more heat resistant in salmon than in cod, depending on the cooking temperature used. This finding shows the importance of the food type. This difference may be due to the higher fat content in salmon (10.56–17.2%, w/w) as compared with cod (0.5–0.8%, w/w). However, in two other studies[11,12], no significant protective effect associated with fat in ground beef could be demonstrated. Ben Embarek and Huss state that the reason for this could be that in both these studies the fat was added to the ground meat and, thus, may not have the same protective effect as naturally fatty meat tissue. Gaze *et al.*[13] recommend that products should be held at 70°C for 2 min, which should be more than sufficient to eliminate *L. monocytogenes* in sous-vide-cooked uncured fish fillets; such treatment produced a 12 log cfu reduction for the most resistant strain tested in salmon, the most protective environment.

Vegetables are often considered to be too poor in nutrients to support the growth of toxin-producing non-proteolytic *C. botulinum*. Carlin and Peck[14] investigated growth (observed as gas production) and toxin production in cooked vegetables that were inoculated with *C. botulinum* after cooking and incubated anaerobically at 30°C for up to 60 d. Growth of non-proteolytic *C. botulinum* was observed within 4 d of inoculation in several vegetables, namely mushroom, spinach, potato, bean sprout, cauliflower, asparagus, broccoli and kale. The presence of toxin was subsequently confirmed in these vegetable samples. The pH values of these vegetables were among the highest of a variety of vegetables tested (pH range 6.39–5.03), although the pH of kale was close to 5.0, which is generally considered as the lower limit for the growth of non-proteolytic *C. botulinum*. In five other vegetables (sweet corn, sweet potato, courgette, white cabbage and leek; pH range 5.33–5.15), gas formation was not observed, but the presence of toxin was detected at the end of the incubation period. Neither growth nor toxin production were observed in tomato preparations, garlic, buttersquash, chicory, green bean, celery, fennel, Brussels sprout, parsnip, turnip, carrot, onion, green pepper and mangetout pea (pH range 5.65–4.23).

Results from a study investigating the influence of various food components on the growth and survival of pathogens (*L. monocytogenes* and non-proteolytic *C. botulinum*) in ready-to-eat foods have been published[15]. In addition to the pH and a_w of the food, important food matrix effects that have been identified are the presence of osmoprotectants (e.g. proline, betaine, carnitine), of essential amino acids both in the free form and in small peptides, or of lytic enzymes (e.g. lysozyme).

Lysozyme may be present in many foods; it is relatively heat resistant and may remain active in some pasteurized products. Other lytic enzymes that cause germination of heat-damaged spores may also be present in foods. Peck *et al.*[16] studied the effects of heating the spores of several non-proteolytic strains of *C. botulinum* at 85°C; enumeration of the survivors on a high-nutrient medium indicated that a 5 log cfu reduction was achieved in less than 2 min. Enumeration of the survivors on a medium containing added lysozyme revealed that heating at 85°C for 5 min resulted in an estimated 2.6 log cfu reduction in spores of strain 17B (type B). Maximum recovery of most of the strains was achieved with a lysozyme concentration of 5–10 μg/ml. It is likely that the heat treatments inactivated the spore germination system. Diffusion of lysozyme into these spores probably caused degradation of the cortex, allowing hydration of the core and spore germination. These findings are important in the assessment of heat treatments required to ensure the safety with respect to non-proteolytic *C. botulinum* for extended storage of sous-vide foods.

In conclusion, the nature of the food (fat content, pH, a_w, presence of osmoprotectants, essential amino acids, lytic enzymes) is an important determinant of the lethality of a heat treatment and also of the possibility of the growth of pathogens. This implies that no single, simple rule can be applied to ensure the safe processing of all sous-vide products.

Spoilage flora of sous-vide products

Although most of the studies concerned with microbiological aspects of sous-vide products focus on pathogens, especially non-proteolytic *C. botulinum* strains, some studies are also concerned with the spoilage flora of sous-vide products.

Shelf-life studies were carried out on a minimally processed sous-vide spaghetti and meat-sauce product that was subjected to heat processing at 65°C (for 71 or 105 min) and at 75°C (for 37 or 40 min); treatment at both temperatures was equivalent to a 5 or 13 log cfu reduction of *S. faecium*[17]. Products stored at 5°C had a shelf life of ≥35 d irrespective of the processing treatment. However, in the case of those products stored at 15°C, the packages were visibly swollen, owing to additional CO_2 production, after 14–24 d, depending on the severity of the heat processing treatment, and the products had a distinct fruity odour when opened. A large population of the initial bacterial load was not totally inactivated at 75°C, only thermally injured, and therefore able to increase to high numbers in products stored at 15°C. The significance of these results is that minimally processed foods may contain a large proportion of thermally injured cells that are able to undergo repair during storage, particularly at temperature abuse conditions, and reach levels of public health concern. Initial spoilage microorganisms consisted predominantly of *Bacillus* species. However, after 7–12 d at 15°C, the spoilage pattern changed, with lactic acid bacteria accounting for almost all of the spoilage microorganisms. The fact that they became the predominant spoilage microorganisms in minimally processed foods, particularly in products heated at 75°C for a time period equivalent to a 13 log cfu reduction, is somewhat surprising. As lactic acid bacteria increased in number, a concomitant increase in the production of CO_2 and lactic acid and a drop in the pH of the product occurred. This study shows that physical, chemical and microbiological changes can, in some cases, be used as indicators of shelf-life acceptability in minimally processed sous-vide products. Changes in package volume, odour and/or colour and bacterial counts, particularly lactic acid bacteria, can be used as indicators of spoilage. The survival and growth of *Bacillus* spp. spores in minimally processed products is of concern because it implies that *C. botulinum* spores could also survive, if present, and may grow and produce toxin. However, at the lower processing times and/or temperatures used, the spoilage trends observed in this study suggest that *C. botulinum* would probably be outgrown by lactic acid bacteria; such products would become visually swollen as a result of CO_2 collecting in the headspace and therefore rejected by the consumer. However, this safety concern is more serious for products processed at the slightly higher temperatures that are sufficient to inactivate lactic acid bacteria and/or other microbiological indicators of physical and chemical spoilage in sous-vide products.

Legislation and good manufacturing practice in different countries

In most countries, food business operators are required not only to comply with general and specific hygiene rules, but also to develop procedures for food hygiene based on the principles of the HACCP system. Table 2 summarizes the legislation regarding the cooling of cooked products in some European countries. It is clear that we are still far from reaching a set of harmonized rules.

Several organizations are in the process of developing codes of practice for industry covering extended-life chilled foods. A code of practice can be advisory rather than prescriptive in form, allowing flexibility of operation. Codes can also be updated more easily than legislation to take account of changing industry practices.

Table 2. Cooling legislation for cooked products in some European countries

Country	Cooling after heating	Cold storage
Belgium[a]	Immediately	7°C
France[b,c]	To 10°C within 2 h	0–3°C, 4°C
Spain[d]	Not specified, specific for each product	0–3°C
UK[e]	As fast as possible	8°C

[a] Data taken from Ref. 28
[b] Data taken from Ref. 29
[c] Data taken from Ref. 30
[d] Data taken from Ref. 31
[e] Data taken from Ref. 32

Compliance with non-statutory codes of practice cannot be enforced, only recommended.

A report on the potential hazards of vacuum packaging and associated processes, such as sous-vide cooking, carried out by the Advisory Committee on the Microbiological Safety of Food, has been published in the UK[18]. The Committee recommended that a comprehensive and authoritative Code of Practice for the manufacture of vacuum-packaged and modified-atmosphere-packaged chilled foods, with particular regard to the risk of botulism, should be drawn up.

The Committee recommends further that, in addition to chill temperatures, which should be maintained throughout the chill chain, the control factors listed below should be used singly or in combination to prevent the growth of, and toxin production by, psychrotrophic *C. botulinum* in prepared chilled foods with an assigned shelf life of more than 10 d.

- Heat treatment at 90°C for 10 min at the core or a heating process that produces the equivalent lethality.
- A pH of ≤5 throughout the food and throughout all components of complex foods.
- A minimum salt concentration of 3.5% in the aqueous phase throughout the food and throughout all components of complex foods.
- An a_w of ≤0.97 throughout the food and throughout all components of complex foods.
- A combination of heat and preservative factors that can be consistently shown to prevent the growth of, and the production of toxin by, psychrotrophic *C. botulinum*.

The Committee is concerned about the non-uniformity of temperatures produced by sous-vide cooking equipment, and recommends that the cooking of sous-vide products should not be undertaken unless operators have the appropriate technical expertise to ensure that pasteurization equipment and operating procedures are adequately designed and tested to heat all containers uniformly and to a given temperature during each cycle. The Committee recommends that, because of the potential lack of control over the cooking or reheating of foods, cooking or reheating should not be relied upon to destroy any botulinum toxin present in foods.

The European Chilled Food Federation published an update of their guidelines for good manufacturing practice (GMP) of chilled prepared foods[19]. Relevant chilled foods have been divided into categories on the basis of ingredients and processes. Some guidelines are summarized below.

- Safe shelf life must be determined on the basis of product formulation and processing parameters for defined chill storage conditions.
- Safety should be assured by applying HACCP principles.
- It is the responsibility of the management to ensure that all personnel handling chilled foods are given thorough and planned training in all relevant aspects of the production, storage and distribution of chilled foods, as well as in personal hygiene and cleanliness.
- All personnel should be issued with documented company rules with regard to the hygiene policy.
- A heating process must receive prior validation, and critical parameters must be controlled and recorded where appropriate.

The recommendations of the US Food and Drug Administration (FDA) for sous-vide processing are listed below[20].

- Sous-vide products should be produced and distributed with a HACCP approach.
- In addition to HACCP, GMP sanitation guidelines should be strictly followed.
- In addition to the primary barrier of refrigeration, multiple barriers or hurdles should be incorporated into sous-vide products. Validation of the efficacy of multiple barriers should be accomplished with either inoculated pack studies or challenge studies.
- Because temperature abuse is common, sous-vide processors should use time–temperature recorders to monitor a product's temperature history. Also recommended is the use of individual time–temperature integrators on each package to indicate if temperature abuse has occurred and whether a potential hazard exists.

The FDA insists on multiple barriers in addition to refrigerated storage. The apparent concern of the FDA is that vacuum packaging represents an unusually risky food-packaging method that will lead to a greater occurrence of the outgrowth of *C. botulinum*. However, food does not need to be in a vacuum bag to have an oxidation–reduction potential (ORP) that is low enough to permit the growth of *C. botulinum*. Snyder[21] measured the ORP in four food items purchased at a local food market delicatessen, which were not specially packed. At the delicatessen, three of the dishes, Lasagna, Dressy Chicken and Chicken à la King, were dished up hot, at 65.5°C, from pans on a steam table, whereas the Deluxe Chicken Salad was dished up cold, at 4.5°C, from platters in the cold, refrigerated display case. The dishes were each packed in small plastic take-home containers with lids. The thickness of each of the products was ~3 cm. It is apparent from the data collected in this study (see Table 3) that the ORP of typical foods sold in delicatessens, which will also be found in typical food-service operations, is more than sufficiently reduced, and that *C. botulinum* will grow, given the opportunity. In all four foods tested, the pH was sufficient to allow the growth of *C. botulinum*. According to Snyder, no new hazards are likely to be created by placing food in a plastic bag, as is done in sous-vide cooking, than are encountered for other current methods of packaging food.

To summarize this section on legislation and GMP recommendations: it is clear that there is still a lot of

Table 3. Temperature, pH and oxidation–reduction potential (ORP) of typical delicatessen food items[a]

Food item	Temperature (°C)[b]	pH	ORP (mV)
Lasagna	58	4.7	−26
Deluxe Chicken Salad	14	5.5	−23
Dressy Chicken	52	5.7	−125
Chicken à la King	57	6.1	−198

[a]Adapted from Ref. 21

[b]The temperatures were those of the food about 15 min after they were bought from the delicatessen and had arrived at the laboratory for testing. The salad had been stored in the delicatessen at 4.5°C, and the other three dishes at 65.5°C

confusion about, for instance, the optimal temperature for cold storage, optimal cooling rates, and how to identify the critical control points. Later this year, under a European Union project, scientists, food manufacturers, regulators and consumer representatives will work on harmonizing safety criteria for minimally processed foods.

Equipment

Sous-vide cooking is mainly used in France, Belgium and The Netherlands, mostly in mass catering but also in high-class restaurants. Because the production volumes and also the types of products are totally different in the two types of catering, the equipment that is used is also different. Sous-vide cooking is a semi-continuous process when performed on a large scale, and a discontinuous process in a small restaurant. As the sous-vide cooking process relies on the strict control of temperature, temperature-measuring devices should be accurate. Overviews of the industrial equipment and equipment used in the catering industry have been produced by Schellekens and Martens[1] and by Peyron[22]. New approaches to equipment design include the use of computational fluid dynamics[23,24] and the use of model-based control design[25].

Sensory and nutritional aspects

There is little published research and a lack of comparable data on sensory and nutritional aspects of sous-vide cooking.

A comparison has been made between sous-vide cooking and roasting of pork meat[26]. The centre temperature during sous-vide cooking (with steam) was 65°C, whereas the centre temperature during roasting (air temperature 180°C) was 75°C. This test was performed with meat from four different breeds of pigs. After sous-vide cooking, the weight loss was 7.6–12% lower than after roasting. However, because the temperatures applied to the product were different in both methods, it is impossible to tell whether this result is due only to the lower temperature used, or whether vacuum packaging before cooking also had an effect.

In a study by Petersen[27], the effects of sous-vide processing, steaming and traditional boiling of broccoli florets on the retention of ascorbic acid, vitamin B_6 and folate were investigated. The sensory quality of freshly prepared samples was also evaluated. When the three different methods of heat treatment were compared, the retention of all three vitamins examined was lowest for boiling, whereas retention was greatest for sous-vide processing, and a little lower for steaming (Table 4). With sous-vide processing, ascorbic acid retention was highly dependent on the degree of vacuum in the package. The retention of vitamin B_6 was independent of the degree of vacuum. Sensory evaluation revealed that freshly prepared sous-vide-cooked and steamed broccoli florets generally had higher acceptability than boiled ones (Table 5).

The effects of sous-vide pasteurization compared with conventional heating on the stability of fatty acids extracted from a seal-meat product have been investigated (S. Ghazala and E.J. Aucoin, unpublished). Lipids in seafoods readily undergo oxidation because they are rich in polyunsaturated fatty acids. Secondary oxidation products of the lipids significantly lower the quality of fish and fish products from the point of view of acceptability and nutrition. The retention of unoxidized unsaturated fatty acids was generally higher in products cooked at the sous-vide pasteurization temperature of 65°C than in those prepared at the higher temperatures (up to 85°C) used for conventional cooking. In the case

Table 4. Theoretical 5-min losses[a] of nutrients from broccoli following different heat treatments[b]

Treatment	Ascorbic acid	Vitamin B_6, total	Folate
Boiling	36%	55%	39%
Steaming	0%	17%	12%
Sous-vide processing	0%	3%	3%

[a]Instead of using the actual cooking times, the equivalent times at a constant temperature of 100°C were used. The 5-min losses were chosen because 5 min is a realistic processing time for broccoli florets

[b]Adapted from Ref. 27

Table 5. Sensory evaluation of freshly prepared broccoli, represented by mean scores from two sessions with a trained panel consisting of eight members[a,b]

Treatment	Broccoli flavour	Bitter taste	Texture	Colour	Overall
Boiled	49	16	45	78	55
Sous vide	62	28	31	71	59
Steamed	57	23	50	74	64
LSD	12	10	12	9	8

[a]Adapted from Ref. 27

[b]Each score was obtained as a tick on a 100-mm line, and is represented as the distance in millimeters from the end of the line. A continuous scale ranging from 'little' to 'much', or from 'bad' to 'good' (overall acceptability) was used

LSD, Least significant difference. A significance level of 5% was used of the saturated fatty acids, the difference between sous-vide processing and conventional heating appeared to be minimal. This greater retention might be attributable to the removal of air during sous-vide processing.

Future trends

Worldwide, sous-vide cooking is gaining more and more attention. It is a promising method because it allows cost-effective operations to provide consumers with fresh-like products. Vitamin retention seems to be higher in sous-vide cooking compared with other cook–chill methods. Sensory data are often confusing and difficult to compare. Aspects that need further investigation include:

- the ability of heat-stressed bacteria to recover during extended storage;
- scientifically based norms for pasteurization values, cooling rates, storage temperatures and shelf lifes;
- critical limits for cooling, cold storage and reheating to preserve vitamins;
- products for which sous-vide cooking gives sensory benefits compared with traditional cooking.

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